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# ***Embankment Dam and Spillway Relative Risk Procedures (for Asset Management/Maintenance)***

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# ***Asset Management***

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## **Project Context**

- Improve procedures for evaluating the current state of assets
  - Inspections performed on an annual basis and reports filed with government agencies
- Develop objective procedures for ranking maintenance priorities
  - Limited budgets
  - Ranking process must be uniform across all administrative units

# *Asset Management*

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## **Project Objectives**

- Asset Management Strategy for:
  - Embankment dams
  - Spillways
  - *Concrete dams*

# Asset Management

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## General principles

Identification and ranking of maintenance interventions.

- Current state is determined from site inspection and data from dam/spillway performance evaluation reports (~**component reliability** – REMR scale)
- Importance is based on the contribution of various components to dam/spillway performance (~**for system reliability**), specific for each facility.
- Ranking is established as a function of relative importance and current state of dam components

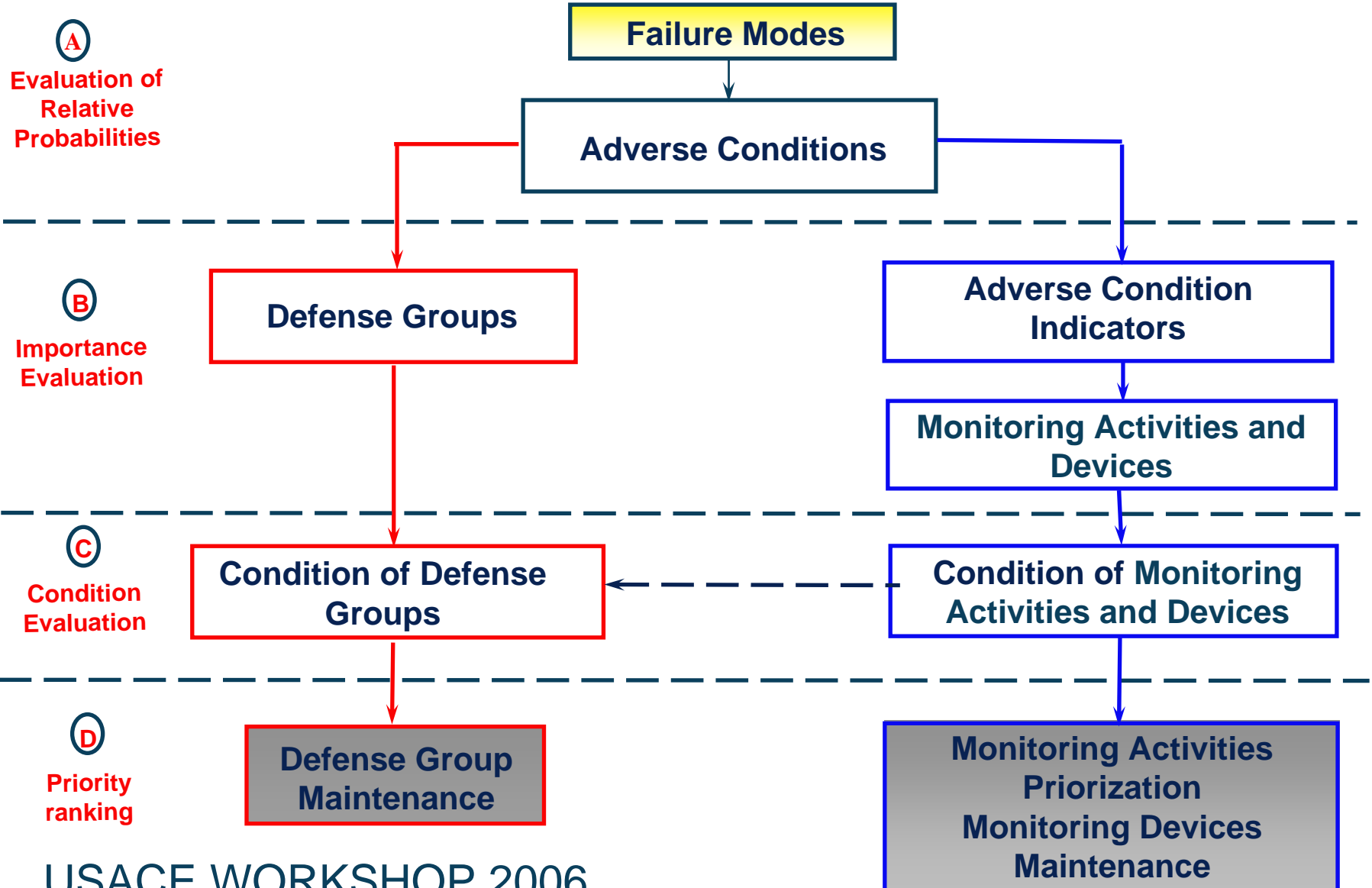
# *Asset Management for Embankment Dams*

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- Initiated in 1995 (Hydro-Quebec with USACE)
- Tested by Hydro-Quebec in 1999 on 25 dams
- Application Guide developed in 2000 by Hydro-Quebec (reduce uncertainty)
- Gradually introduced in all districts
- Adopted by Manitoba-Hydro and Cemagref (France)

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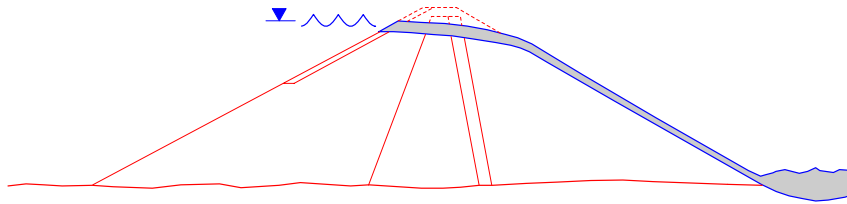
## Methodology



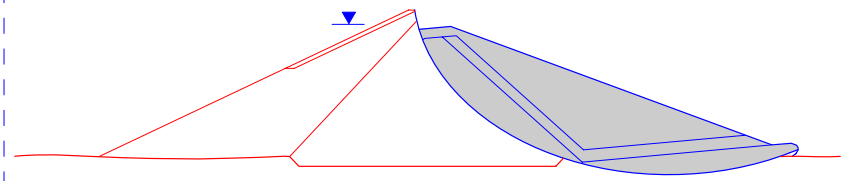
# Asset Management

## THE FOUR MAJOR FAILURE MODES FOR EMBANKMENT DAMS

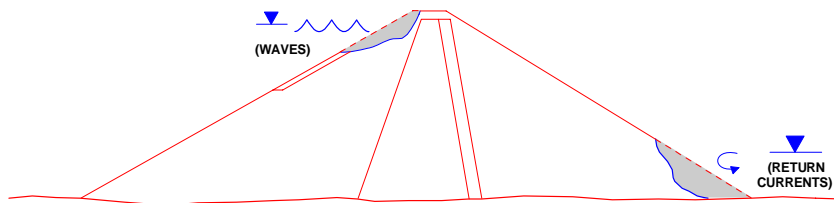
**OVERTOPPING**  
(DUE TO AN INSTRUMENT RISER COLLAPSE)



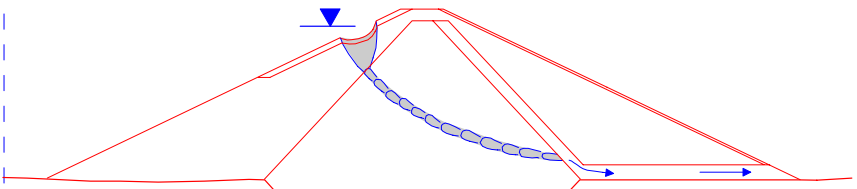
**"MASS MOVEMENT"**



**"EXTERNAL" EROSION**



**"INTERNAL" EROSION**  
(PIPING)



DAM FAILURE DEFINITION: UNCONTROLLED RELEASE OF RESERVOIR

S\_4RUPT.GRF

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## Positive attributes

- |  |
|--|
| • Rock abutment surfaces                               |
| • Low seismicity location                              |
| • Low exposition to wave attack                        |
| • Non erodible core                                    |
| • Embankment made up of filtering material             |
| • Non erodible rock foundation                         |
| • Filters designed according to modern practice        |
| • Reservoir touches dyke only near maximum water level |
| • Freeboard dyke on rock foundation                    |

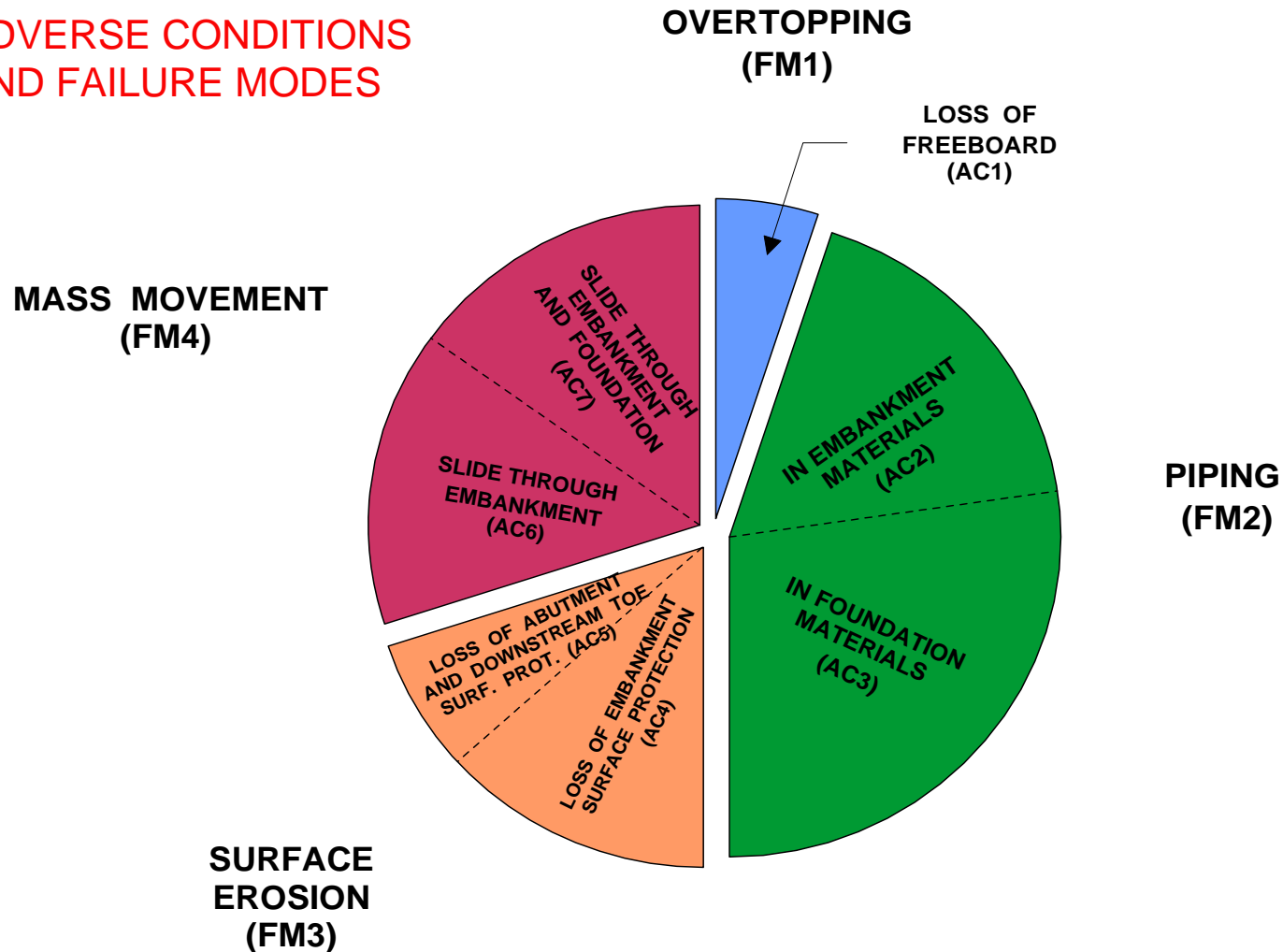
## Negative attributes

- |  |
|--|
| • Spillway operated by other owner                         |
| • Totally submerged downstream toe                         |
| • Locally submerged downstream toe                         |
| • Large water seepage at downstream toe                    |
| • No chimney drain in homogeneous dyke                     |
| • Heterogeneous and permeable foundation materials         |
| • No positive cutoff in permeable soil foundation          |
| • Vertical or sub-vertical abutment                        |
| • Low freeboard  |
| • Potential sinkhole formation near instrumentation risers |
| • High seismicity location                                 |



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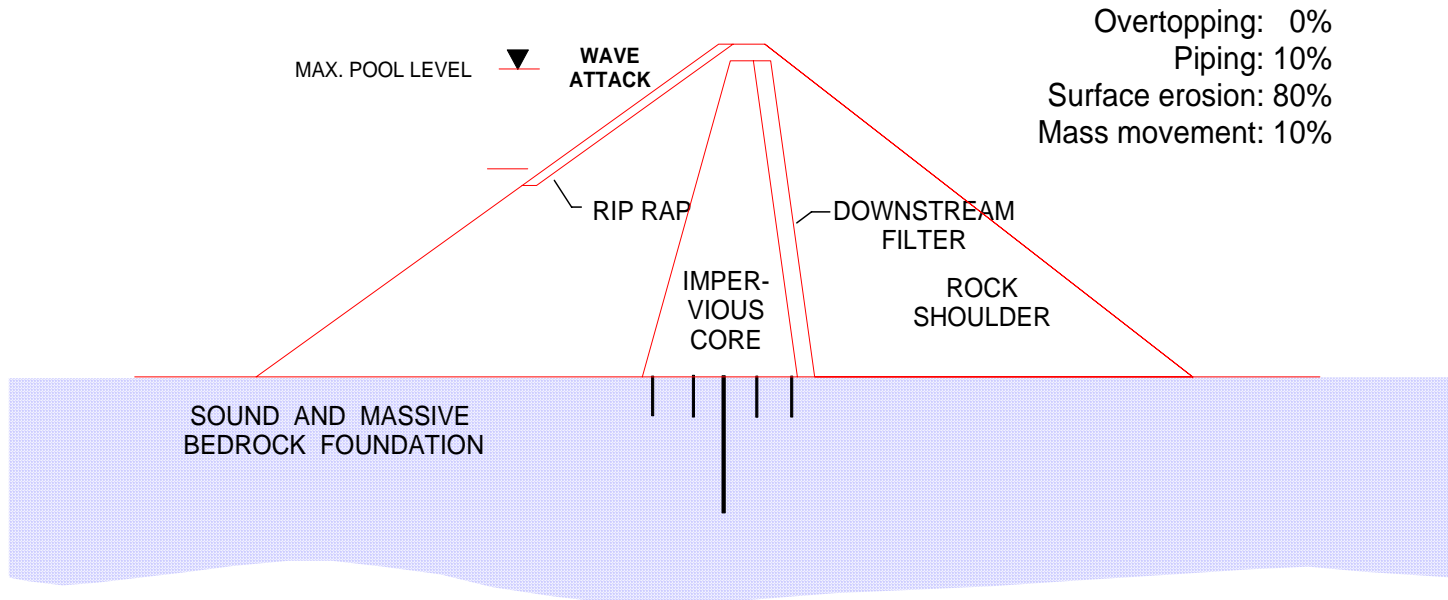
## ADVERSE CONDITIONS AND FAILURE MODES



# Asset Management

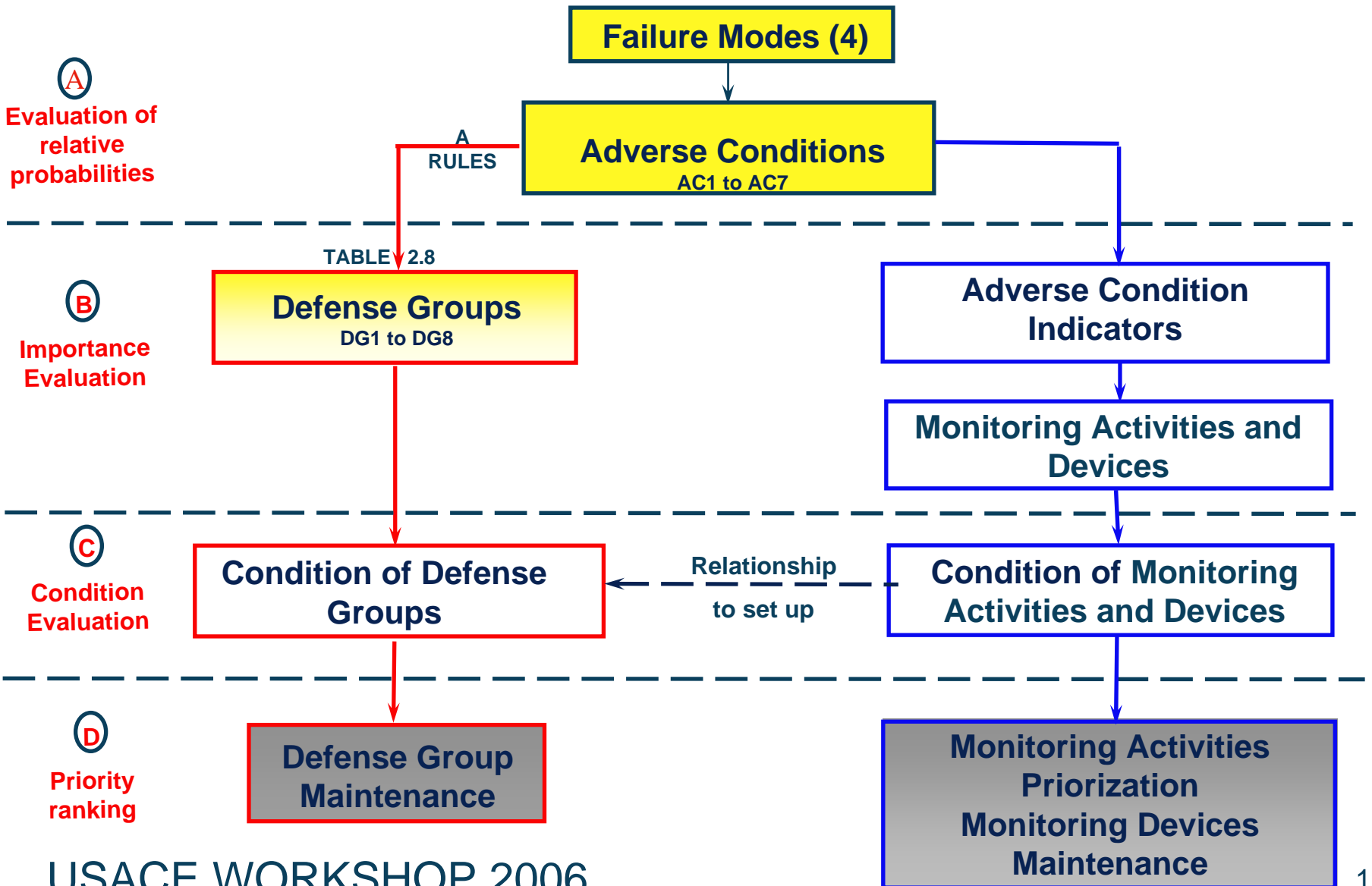
## FAMILY I

### ROCK (OR GRANULAR) EMBANKMENT ON SOUND AND MASSIVE BEDROCK FOUNDATION



MAIN CONCERN:  
RIPRAP EROSION BY WAVE ATTACK  
IN DIFFICULT CLIMATE

# Asset Management

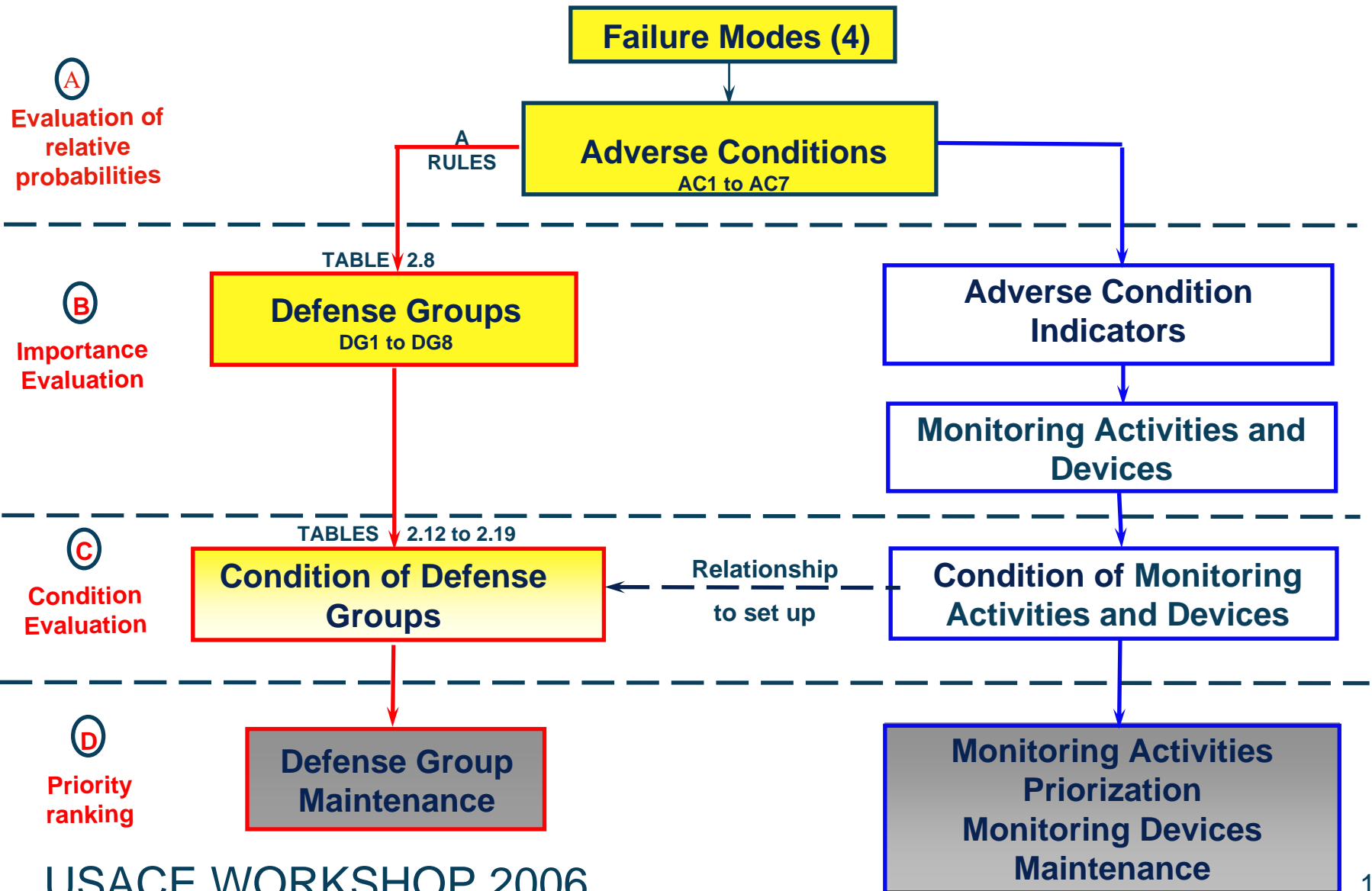


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Defense Groups (DG)	Components
DG1. Maintaining nominal crest elevation	Top of dam
DG2. Filtration control in embankment	Engineered filter materials placed within embankment to prevent the migration of fines
DG3. Pressure control in embankment	Chimney drains, blanket drains, finger drains, impervious core, etc.
DG4. Filtration control in foundation	Engineered filter materials placed over foundation outside embankment to prevent the migration of fines
DG5. Pressure control in foundation	Relief wells, toe drain, positive cutoff, upstream impervious blanket, etc.
DG6. Upstream slope protection	Rip-rap, upstream concrete blanket, etc.
DG7. Crest and downstream slope protection	Stone, vegetation cover, etc.
DG8. Abutment and downstream toe protection	Stone, vegetation cover, etc.

# Asset Management



# Asset Management

## REMR Scale

Zone	Condition index	Condition description	Recommended action
1	85 to 100	<b>Excellent:</b> No noticeable defects. Some aging or wear may be visible.	Immediate action is not required.
	70 to 84	<b>Good:</b> Only minor deterioration or defects are evident.	
2	55 to 69	<b>Fair:</b> Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	<b>Marginal:</b> Moderate deterioration. Function is still adequate.	
3	25 to 39	<b>Poor:</b> Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	<b>Very Poor:</b> Extensive deterioration. Barely functional.	
	0 to 9	<b>Failed:</b> No longer functions. General failure or complete failure of a major structural component.	

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- Condition Table for a Defense Group
  - Define its function (performance based)
  - Define what is an excellent condition (100)
  - Define what is a failed condition (0)
  - Identify indicators of condition
    - Physical measurement
    - Performance level
    - Qualitative observation

# Asset Management

Defense Group DG2. Filtering control in embankment									
Ideal condition	No migration of fines with a designed filtering system.								
Failed condition	Persistent migration of fines.								
	0-9	10-24	25-39	40-54	55-69	70-84	85-100		
Condition description	Failed	Very poor	Poor	Marginal	Fair	Good	Excellent	Given index	Remarks and justifications
Indicators DG IND									
IND2.1. Existence of turbid flows or sand deposition at uncontrolled seepage location in embankment									
• no evidence							100	100	Clear seepage
• evidence of prior occurrence			X	X	X				
• actively occurring	X	X							
IND2.2. Sinkholes or depressions in embankment									
• no evidence							100	100	No noticeable deformations
• evidence of prior occurrence			X	X	X				
• actively occurring	X	X							
IND2.3. Known defect, but with no indicator of distress			X	X	X	X			

Examples of known defects: poor design of internal filter or drainage zone within embankment.



# Asset Management

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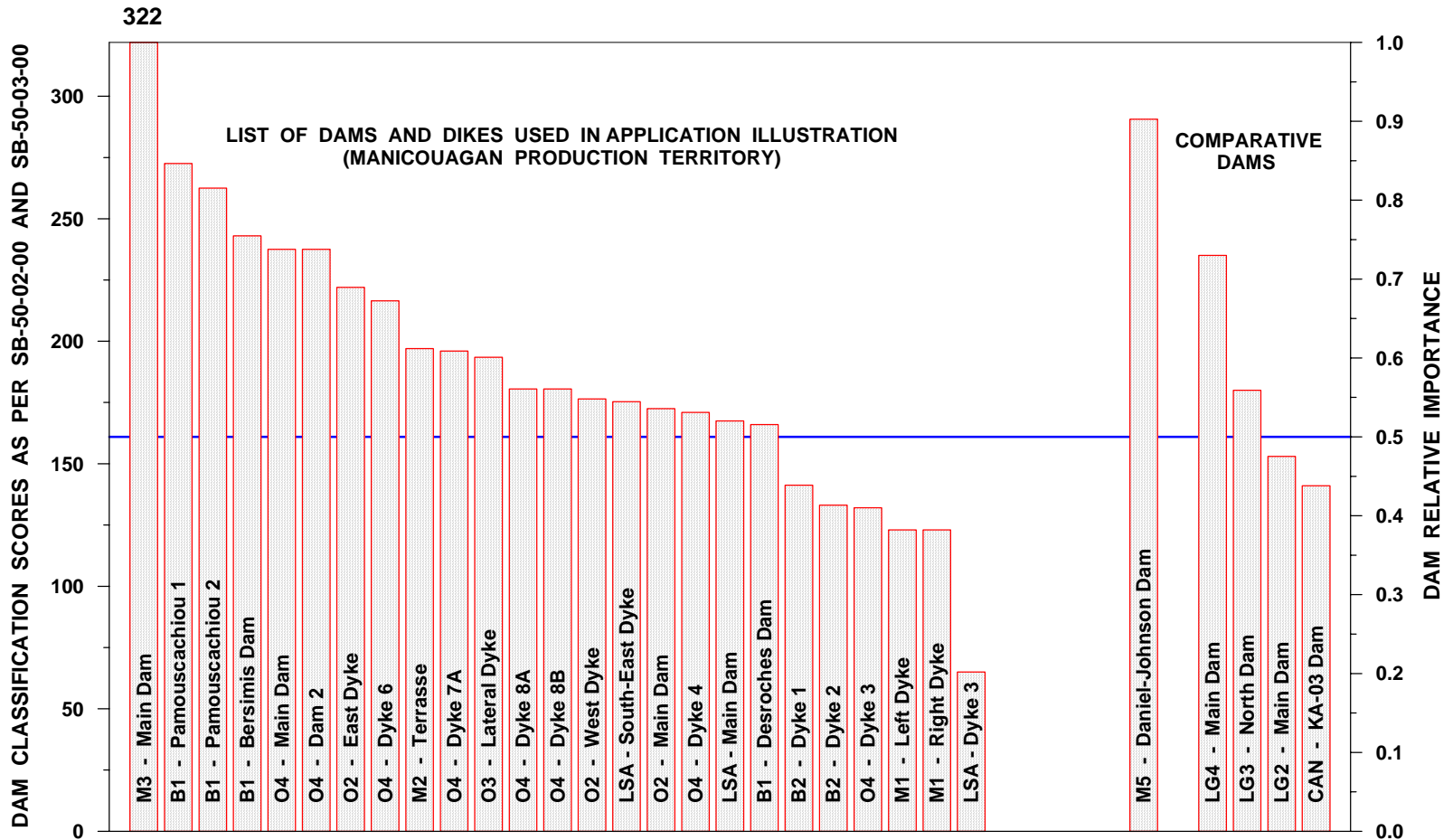
$$PR_{DG_{i,j}} = I_{Dam_j} \cdot I_{DG_{i,j}} \cdot \frac{(100 - CI_{DG_{i,j}})}{100}$$

where

$CI_{DG_{i,j}}$	condition index of Defense Group $DG_i$ of $Dam_j$
$I_{DG_{i,j}}$	relative importance of Defense Group $DG_i$ of $Dam_j$
$I_{Dam_j}$	relative importance of $Dam_j$
$PR_{DG_{i,j}}$	priority ranking of Defense Group $DG_i$ of $Dam_j$

# Asset Management

## HYDRO-QUEBEC DAM CLASSIFICATION SCORES

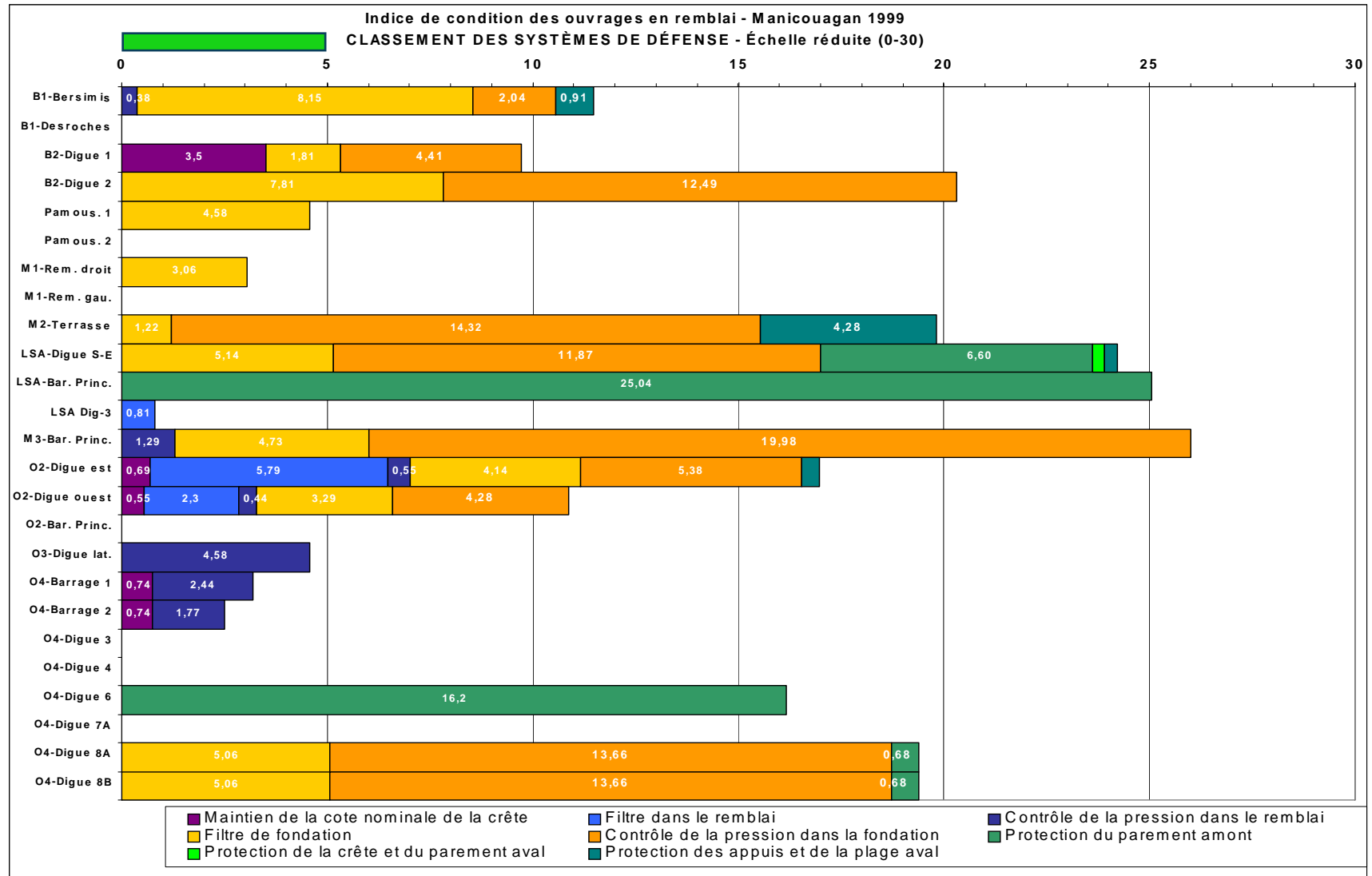


NOTE: DAM CLASSIFICATION SCORES WERE ESTABLISHED BY MANICOUAGAN PRODUCTION TERRITORY

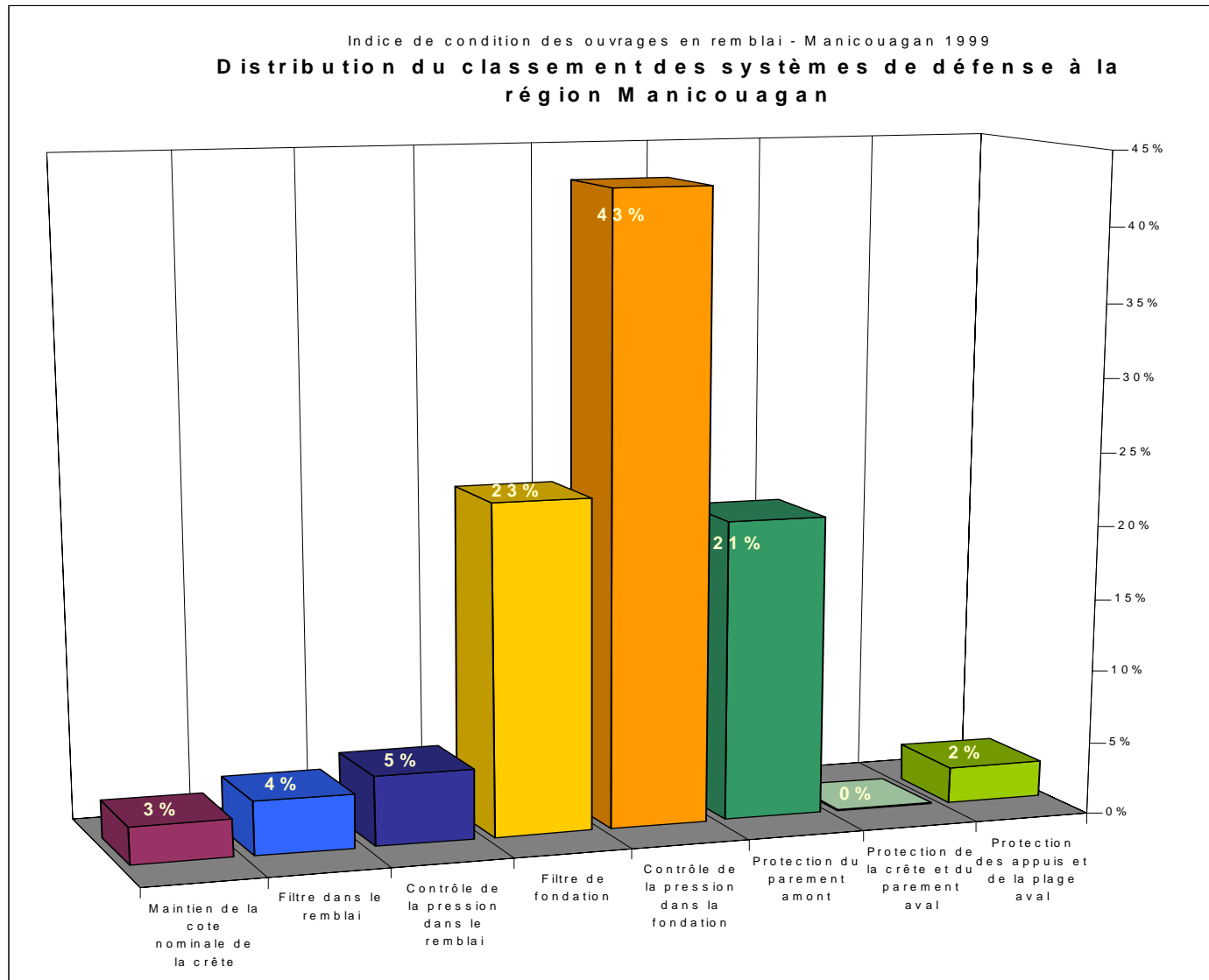
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# Asset Management

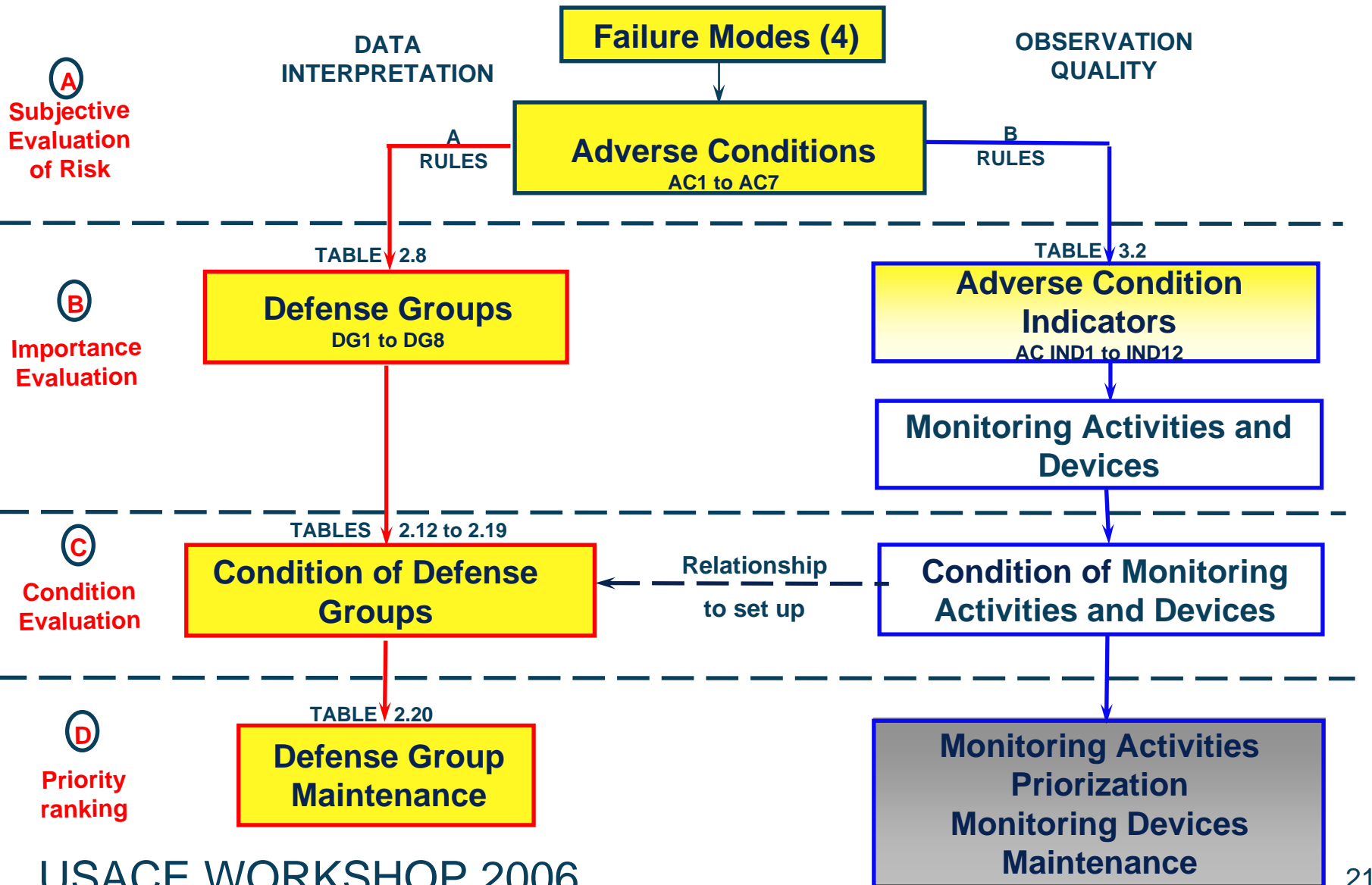
 Pressure control in foundation  
 Upstream slope protection



# Asset Management



# Asset Management



# Asset Management

## Deformation

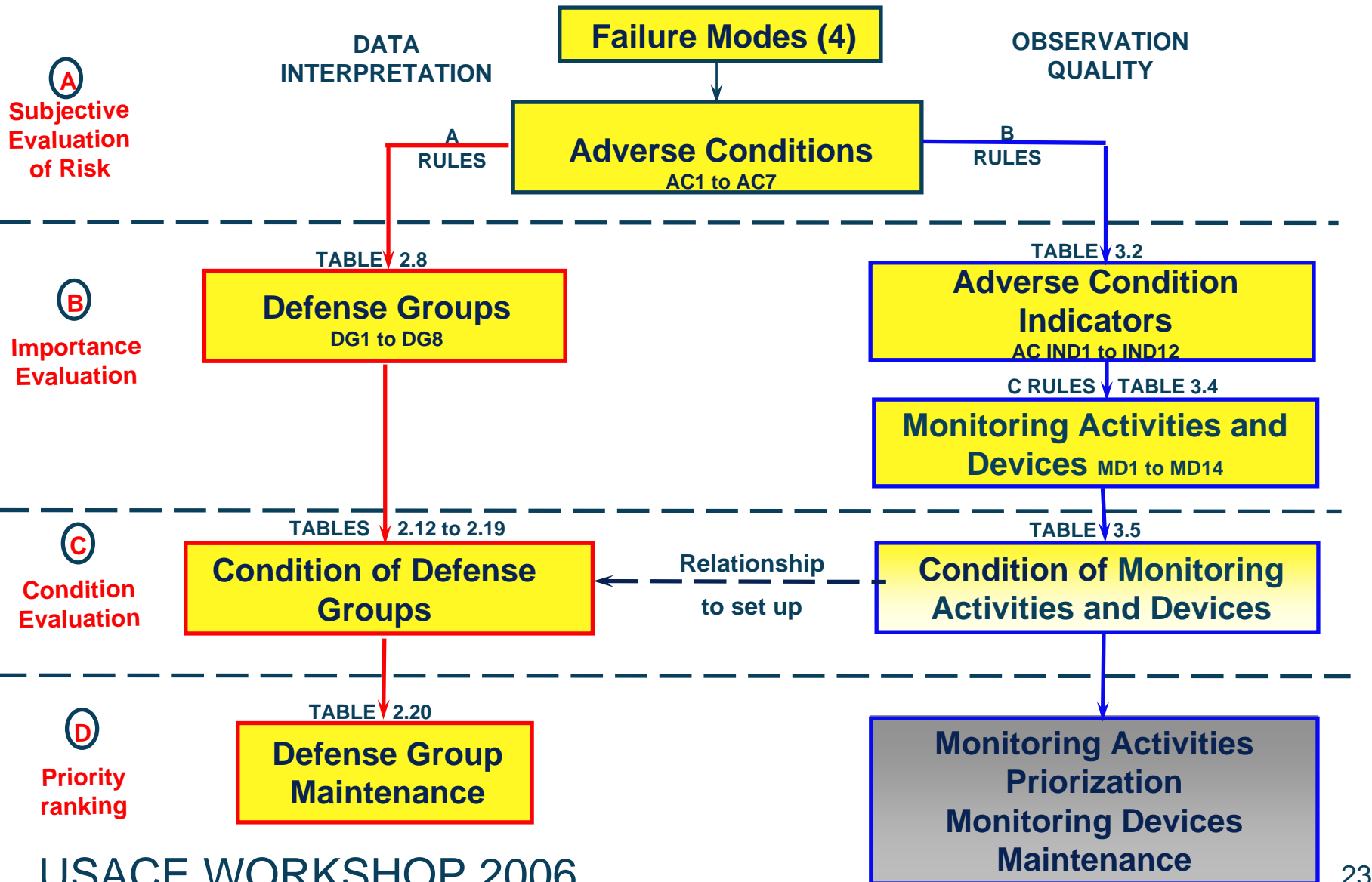
Adverse Condition Indicators (AC IND)	Definitions
AC IND1. Change in geometry on upstream slope	Visible or measurable differences between design geometry and current conditions for the upstream slope.
AC IND2. Change in geometry on crest	Visible or measurable differences between design geometry and current conditions for the crest.
AC IND3. Change in geometry on downstream slope	Visible or measurable differences between design geometry and current conditions for the downstream slope.
AC IND4. Change in geometry on downstream toe area	Visible or measurable differences between design geometry and current conditions for the downstream toe area.
AC IND5. Relative movement between components	Visible or measured evidence of relative displacements between objects resting on the embankment dam and those resting on the foundation.
AC IND6. Change in controlled seepage	Seepage quantities measured at control locations (e.g. toe drains, pressure relief wells)
AC IND7. Uncontrolled seepage on downstream slope	Unplanned and unfiltered surface seepage on the downstream slope (turbid refers to removal of soils).
AC IND8. Uncontrolled seepage on downstream toe area	Unplanned and unfiltered surface seepage on the downstream toe area (turbid refers to removal of soils).
AC IND9. Piezometric levels in embankment	Referring either to the magnitude or as inferred from flow net to calculate gradients.
AC IND10. Piezometric levels in foundation	Referring either to the magnitude or as inferred from flow net to calculate gradients.
AC IND11. Change in vegetation on downstream slope	Visible changes in the amount or coloration of vegetation on the embankment dam or adjacent regions in the general vicinity of the downstream slope.
AC IND12. Change in vegetation on downstream toe area	Visible changes in the amount or coloration of vegetation on the embankment dam or adjacent regions in the general vicinity of the downstream toe area.

## Seepage

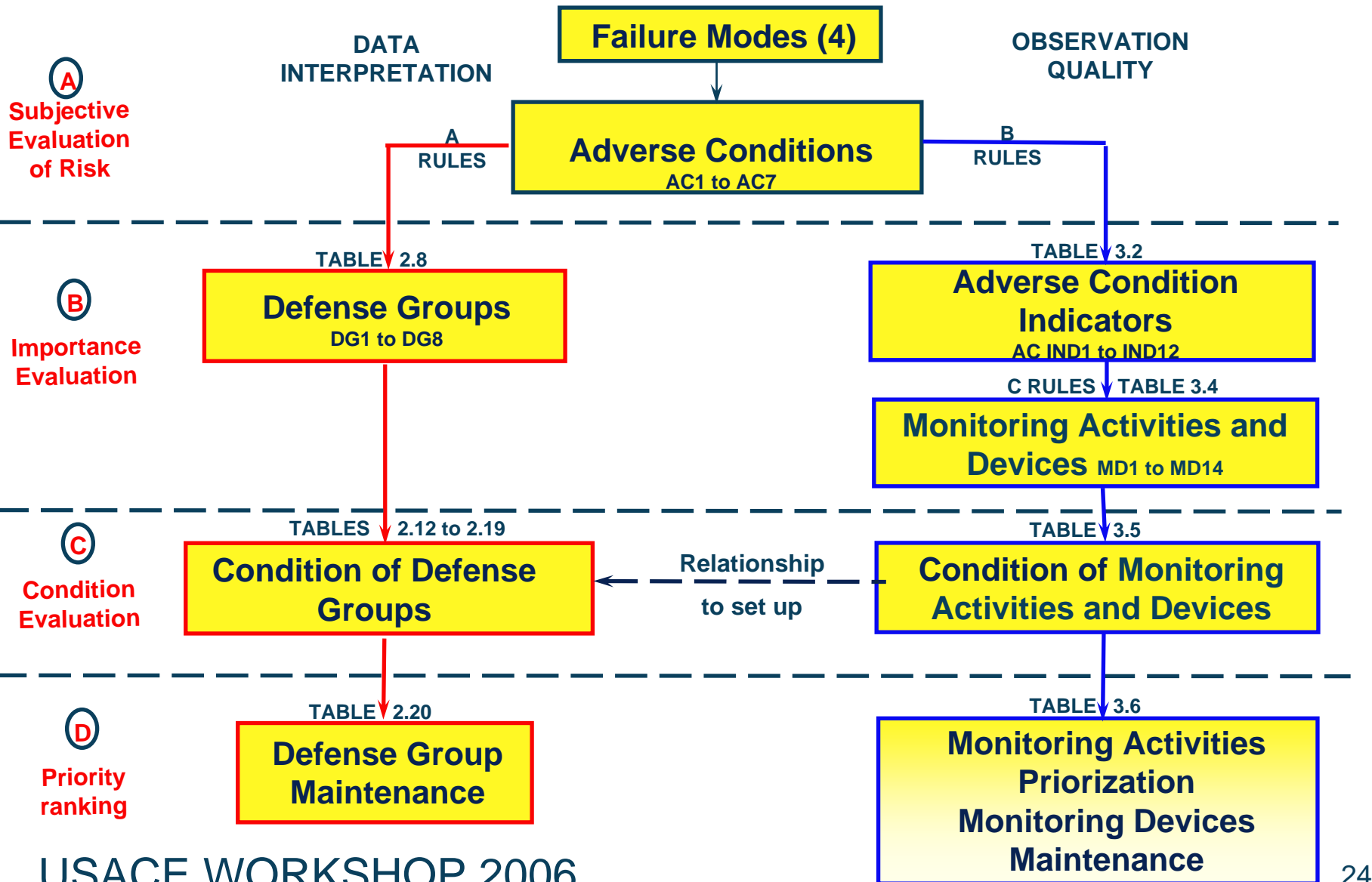
## Pressure

## Vegetation

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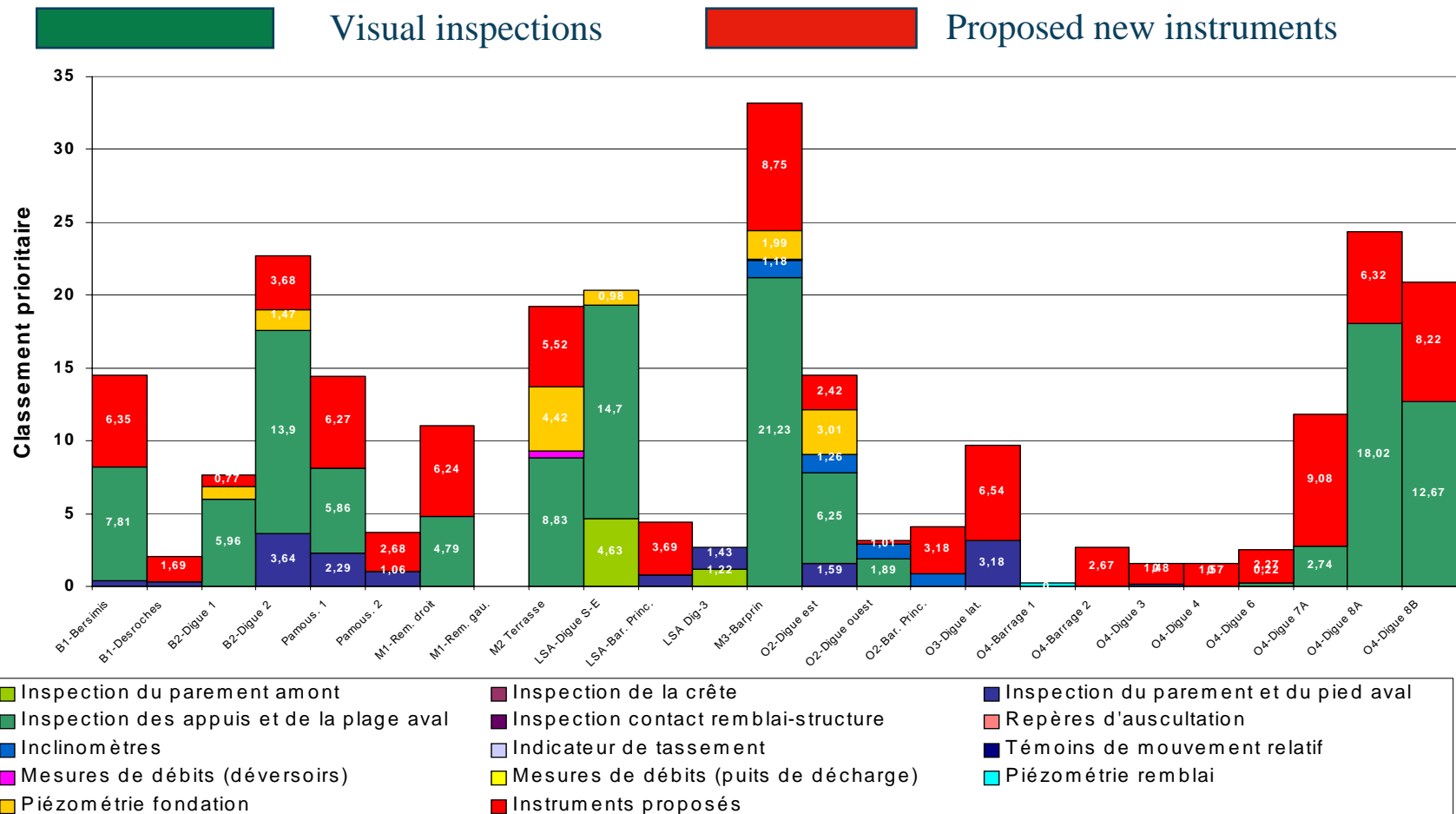
# Asset Management





# Asset Management

Indice de condition des ouvrages en remblai - Manicouagan 1999  
Classement des activités et dispositifs de surveillance -  
Échelle réduite (0-35)



# *Asset Management*

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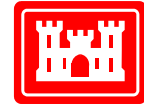
## Spillways

# Asset Management

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## Partners

- U.S. Army Corps of Engineers
- Manitoba Hydro
- Ontario Power Generation
- U.S. Bureau of Reclamation
- Hydro-Québec
- McGill University



US Army Corps  
of Engineers



ONTARIO **POWER**  
GENERATION



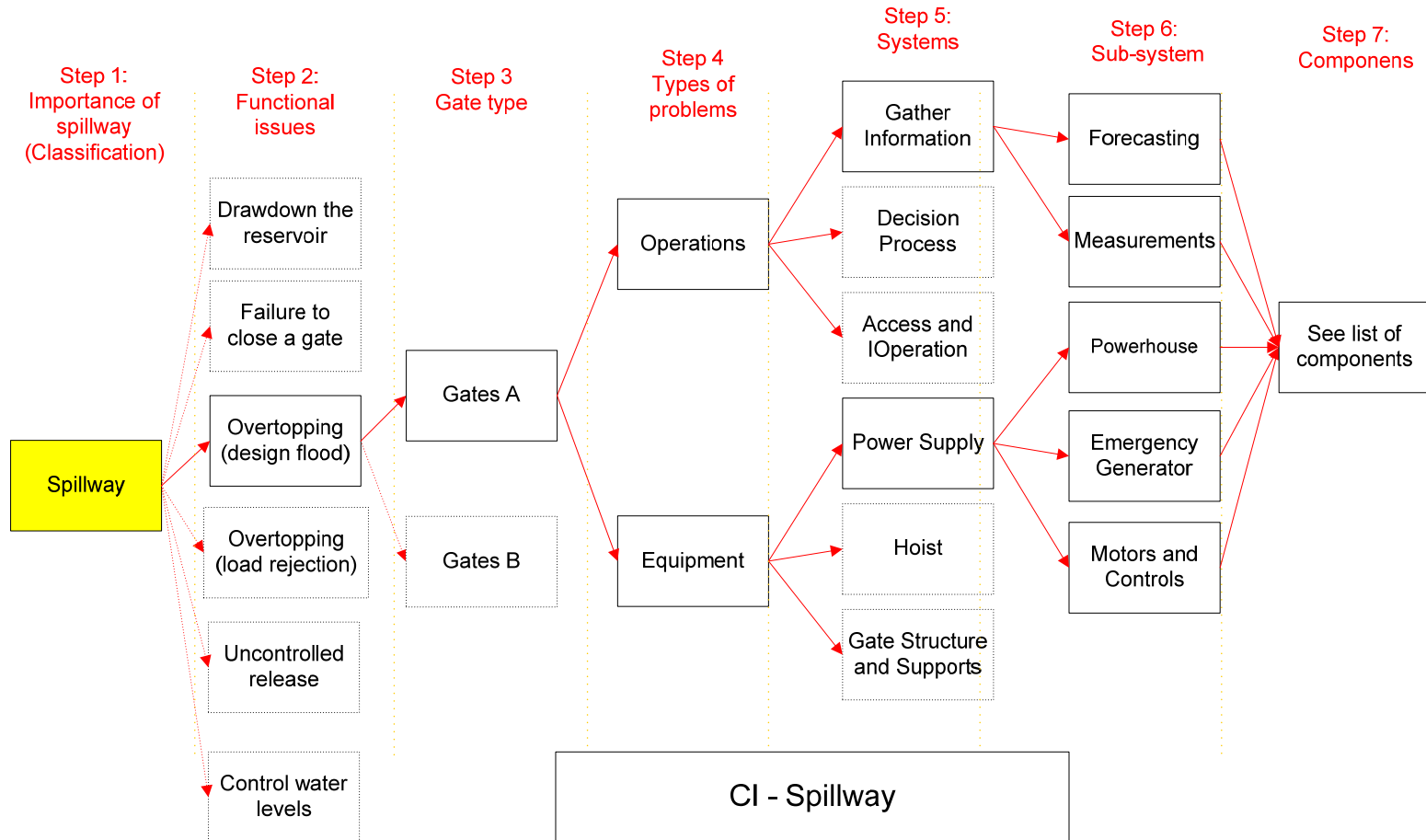
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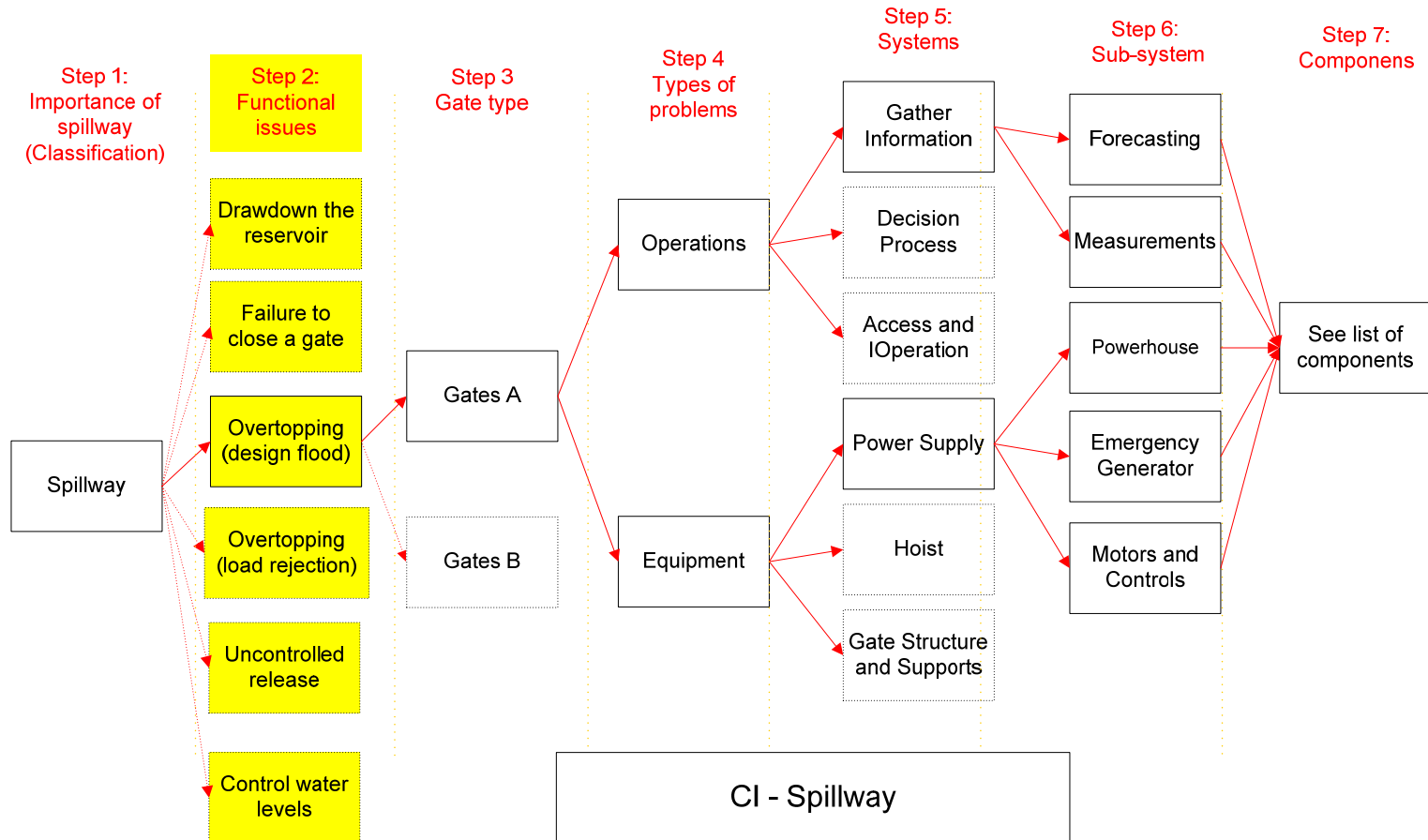
## Importance Factors

- Conceptual model of the spillway (number of gates, lifting devices, etc.)
- Identify major functional issues associated with the spillway
- Relative importance of components for each function (factors considered: role of the component, response time, reaction,...)

# Asset Management



# Asset Management



# Asset Management

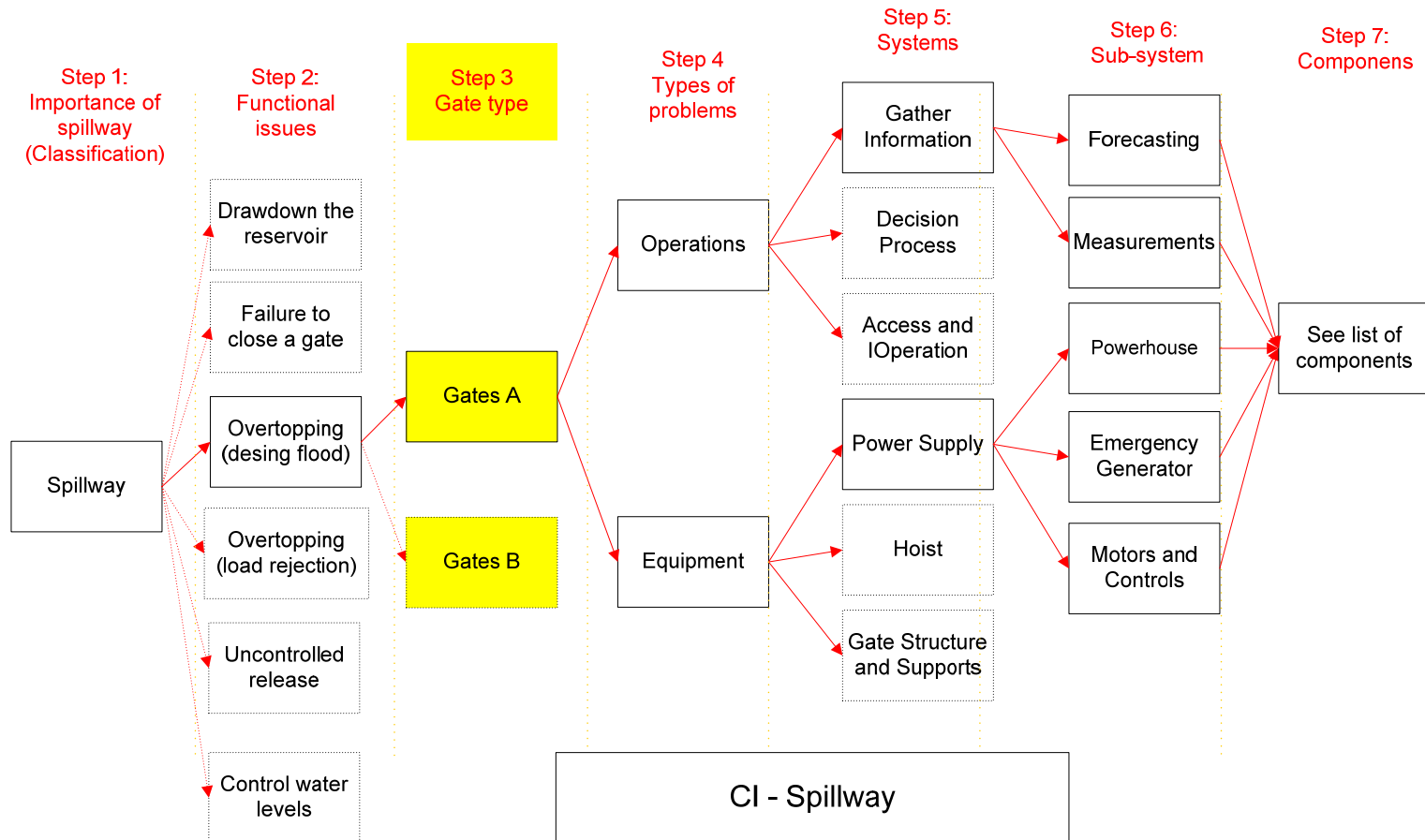
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## Step 2

Functional issues	Definition
Prevent overtopping during a design flood	Ability to operate all gates to achieve full spilling capacity.
Prevent overtopping during load rejection	Ability to spill the powerhouse flow during load rejection
Prevent an unintentional opening of the gates	Structural failure of a gate (blowout) or unintended opening of gate due to inaccurate information or a failure of automatic controls.
Prevent failure to close a gate	Failure to close a gate due to equipment failure or failure to recognize the need to close a gate due to inaccurate information
Drawdown the reservoir	Ability to drawdown the reservoir to prevent a structural failure of the dam or foundation.
Control water levels	For navigation, recreation, water supply, etc.

# Asset Management

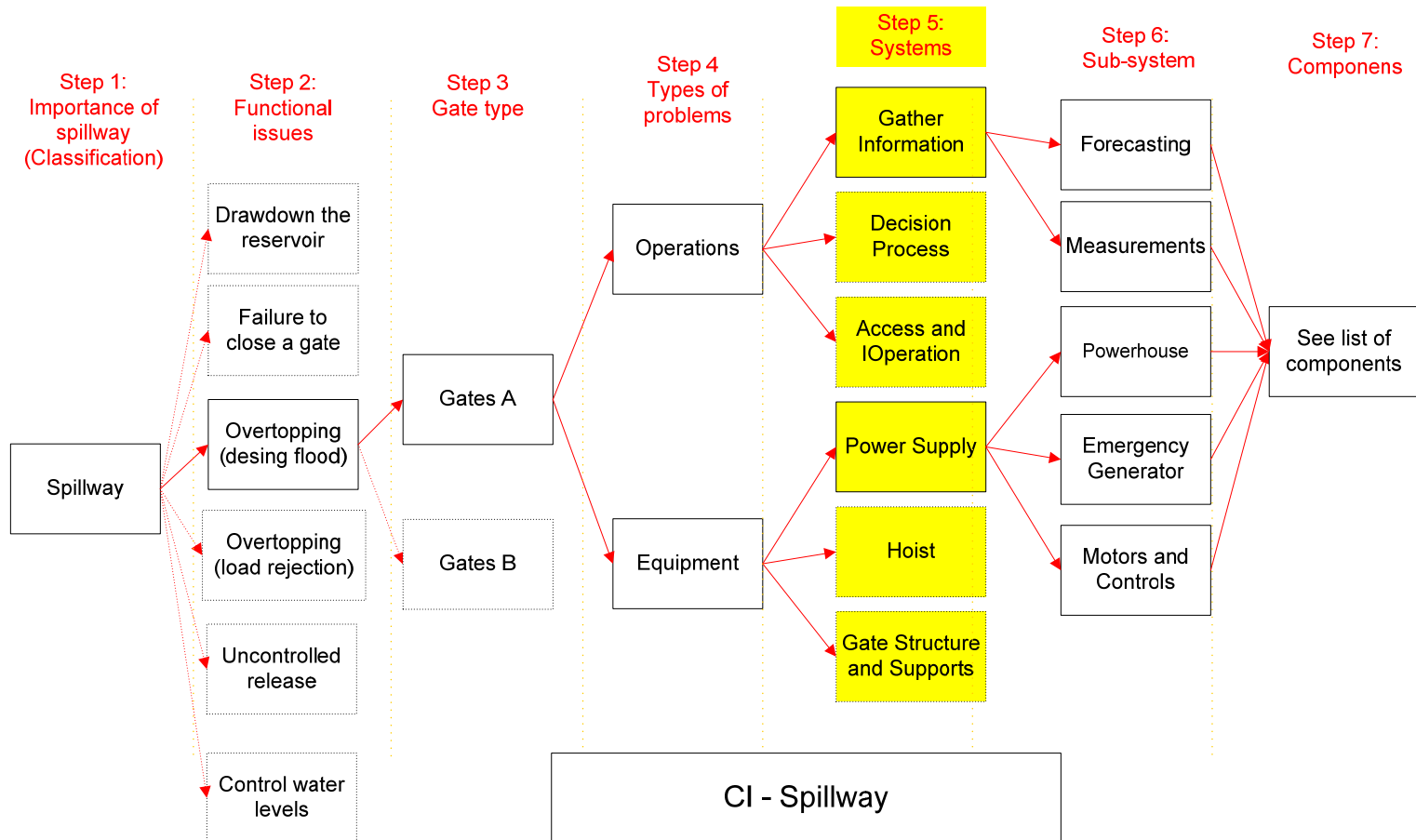
## Spillway





## Spillway





## Spillway



# Asset Management

<b>Screw and Nut (Screw-type hoist)</b>									
<b>Function</b>	Transfer shaft rotation into gate movement								
<b>Excellent</b>	No warping, no wear, geometry according to specs, uncontaminated grease .								
<b>Failed</b>	Warped enough to jam the mechanism, broken, split, missing threads, enough surface damage/corrosion to cause excessive friction								
<b>Indicator</b>	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
	1	2	3	4	5	6	7	S	
No warping, or damage, or wear with adequate lubrication and geometry and works as designed							X		
Surface Contaminants on grease or slight warping on screw with some damage or wear to threads of nut					X	X		60	Slight warping of a screw
Inappropriate lubrication			X	X	X				
Excessive friction/noise, vibration and jumping, presence of metal shavings		X	X						
Warped enough to jam the mechanism; broken, split, missing threads; enough surface damage/corrosion to cause excessive friction	X								

Claude Lemire

Raymond St-Jacques

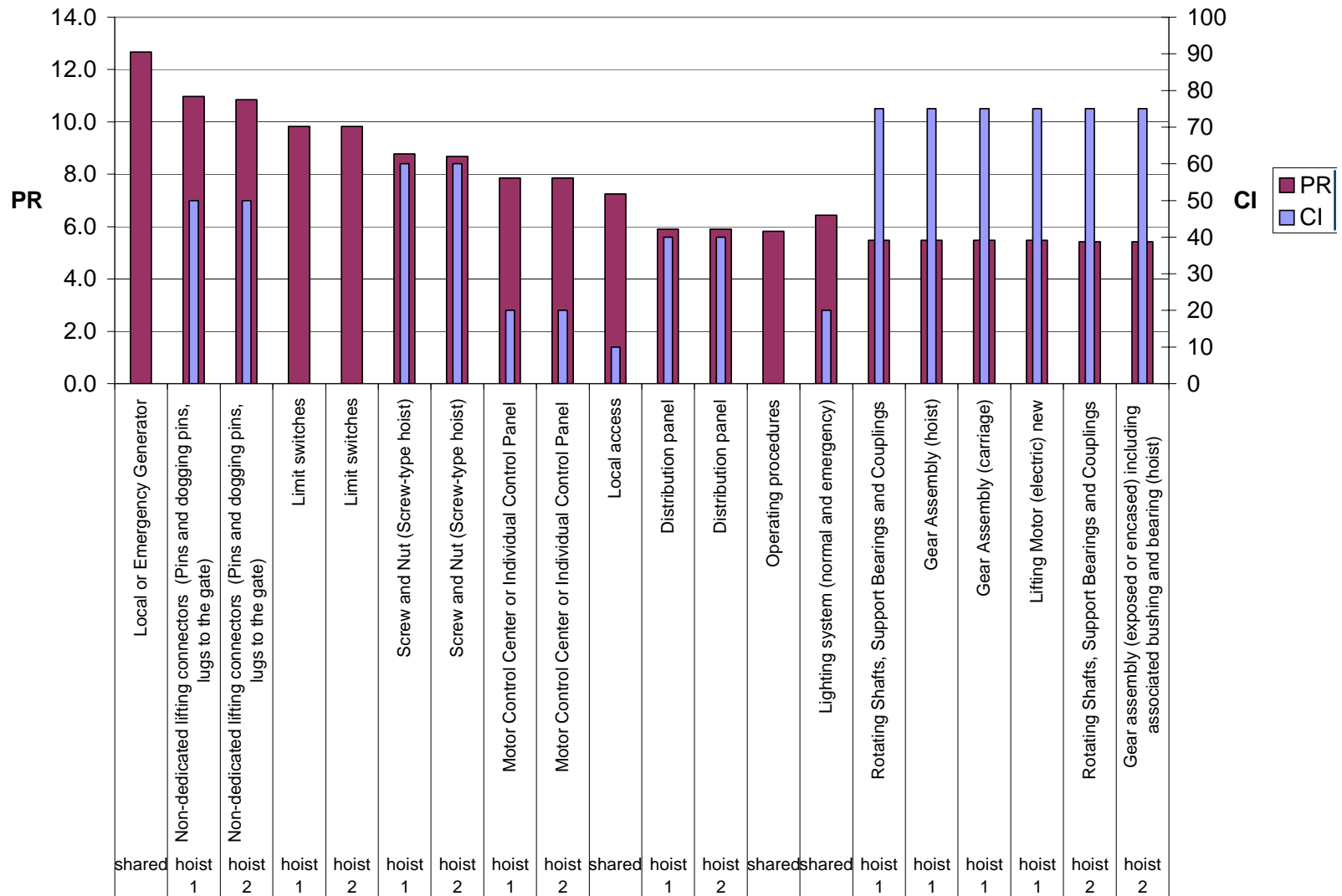
Écrous ont été changé sur le chariot 2.

Does this category apply to the dam being evaluated ? y

(y/n)

CI representing this category (minimum score): 60

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## Conclusions

- Priority ranking identifies most advantageous maintenance activities in terms of dam safety
- Method permits good overview of dam condition and behavior
- Values Dam Safety Engineer technical judgment
- Uniform procedure
- Flexible and adaptable

# ***Asset Management***

**Thank you!**

